

Fracture toughness evaluation on several carbon steels

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Resume

J integrals are measured on the heat treated carbon steel. The properties of fracture toughness are discussed relating to the microstructure, plane strain condition and stress intensity factors. The resistance curve method with compact tension type specimen is employed, and obtained J values are 150 to 470 kN/m. The declination of resistance curves is experimentally evaluated and suggested to use as a tentative value in case of scattered J values or least plot points. The correlation between microstructure and J values is discussed but not clearly analyzed.

I. Introduction

Even in the modern age of engineering, the accident like an airplane crash, the breakage of a bridge or an automobile collision are often reported in the mass media. In many cases the reason of accident is not so simple, but the most cases are accompanied with the deformation of structure or fracture of materials. Therefore some of the accidents might be or might not be avoided by the proper design of engineering or maintenance. From the engineering standpoint, it is assumed that the material does not break at once from a flawless state but a fracture starts from a small size of cracks, and then the growth of those cracks follows. And finally the structure with certain dimension of fault can not withstand the original design stress. This is the concern of modern fracture mechanics. One of the characteristic factor on the metal fracture is the stress intensity factor (K_{Ic}), which evaluates whether the cracks are going to grow or to stay in the same size. But the measurement of K_{Ic} has the difficulty of specimen size. Because the measured K_{Ic} should satisfy the plane strain condition. It turns out sometimes the necessity of relatively large size of test pieces¹⁾. Therefore the measurement of J integral (J_{Ic}) is employed here since it can be measured by relatively compact specimen and it has equivalent validity²⁾. Because of difficulty of experimental standard procedure and the lack of experimental facility, those reliable values are not well established, especially correlating with their fine microstructure of heat treated steel. Here the effort to measure the J_{Ic} values using as possible as standardized resistance curve method on several steels with common microstructures

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is made.

II. Experimental procedure

The steels selected for the experiment are S15C, S25C and S55C. They are heat treated and machined to the compact tension type test pieces. The dimension of specimen is shown in Fig.1. Those geometry is slightly different from ASTM standard³⁾. Test specimens are pre cracked by alternately stressing to create sharp notches. The crack opening displacement (COD) is measured by clip gauge attached to the specimen. The load vs. COD diagrams are plotted by X-Y recorder and the load is applied to the certain extension of a crack, and then the specimen is removed from the testing machine and fractured at cryogenic temperature using liquefied nitrogen. The morphology of fractured surface and the extended crack are schematically shown in Fig.2. The test results are analyzed by the resistance curve method. J values are calculated by the following equation .

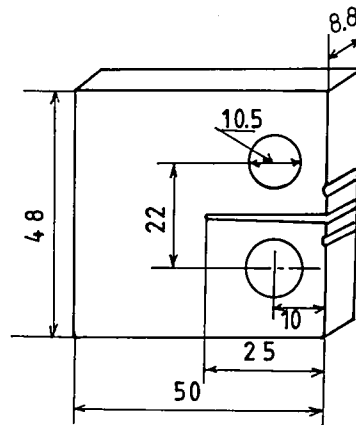


Fig.1 Dimension of compact tension type test specimen

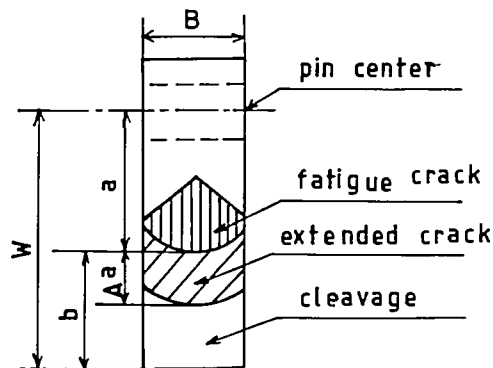


Fig.2 Configuration of chevron type pre-cracked specimen after fracture toughness test

$$J=A \cdot f(a/W)/(B \cdot b) \quad (2.1)$$

A: Energy measured by the diagram of load and distortion

B: Thickness of the specimen

W: Width of the specimen

b: Ligament

f(x): Correcting function

III. Results and discussion

According to the survey of references the reliable J_{Ic} values are not enough reported on the conventional materials. But the application of fracture mechanics on the various field demands the data base of K_{Ic} or J_{Ic} for many conventional materials and for the special steels^{4,5)}. But the complication of testing procedure prevents the supplying the data to this field. Also standard testing method is not established in the present state. The fundamental principle of elastic analysis depends on the plane strain condition. Therefore the measurement of K_{Ic} has to satisfy that condition. Generally the plane strain condition is more easily satisfied in the hard, strong or rigid material which has less ductility. And it has limited accuracy of measured K_{Ic} . But the soft and ductile material deforms in more complicated manner, that means the testing under precise condition of plane strain is difficult. Therefor usually larger scale of test pieces is recommended. But the larger specimen has heterogeneity of macro and micro structure, such as thickness over 50 mm. And also it is difficult to prepare the specimen.

On the other hand the calculation of J integral needs more complicated equation but it encloses the plane stress conditions. The actual experimental results show various morphology of the fracture surface, especially at the crack tip area. The main subject of this paper is to analyze the effect of microstructure on the fracture toughness, therefore the appearance of fractured surface and the irregularity of macroscopic test condition show the validity of employing J integral.

J_{Ic} measurement includes the plane strain and stress condition and other energetic factors, so that it is valid in the practical use and the J_{Ic} value can be evaluated from the normal size specimen. That is the important reason why J_{Ic} is measured instead of K_{Ic} .

Fig.3 shows the COD vs. applied load of the annealed S15C steel using the compact tension specimen. The J value is calculated from this diagram and equation of (2.1). The extended crack length which is measured after the unloading, is controlled by the lateral observation with some kinds of experience. That means, it is difficult to get exactly intended values. The effect of fatigue pre crack loading is not negligible, but the crack tip is sharper than any other machinery. It is always employed in this type of experiment. Therefore the shape of COD vs. applied load diagram and the crack tip configuration depend on the crack length and other factors. But principally it

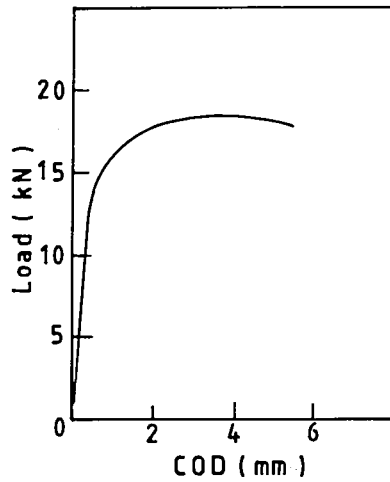


Fig.3 Load vs. COD diagram measured for S15C steel

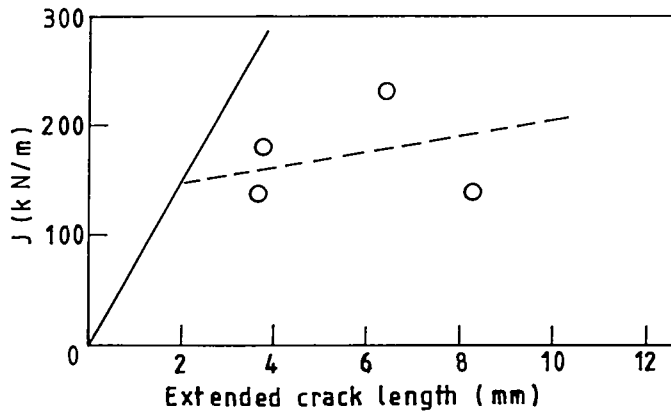


Fig.4 Resistance curve method for evaluation of J_{Ic} on S15C steel

should be shown similar behavior. And the example of original datum for J-R curve is shown in Fig.4. If the experimental results have scattered widely, the drawing of resistance curve is not easy, even if the regression analyses are used. Therefore the reasonable declination of resistance curve is proposed by the regression analysis of confident test results shown in Fig.5. The following is the declination obtained.

$$dJ/da = 6.97 \text{ kN/m/mm} \dots (3.1)$$

This value means if the data are not enough to draw resistance curve tentative use of this value is recommended.

The obtained J values are listed in Table 1. The J values are scattered between 150 to 370 kN/m and the reference data 138-395 kN/m³⁾. These scattered results

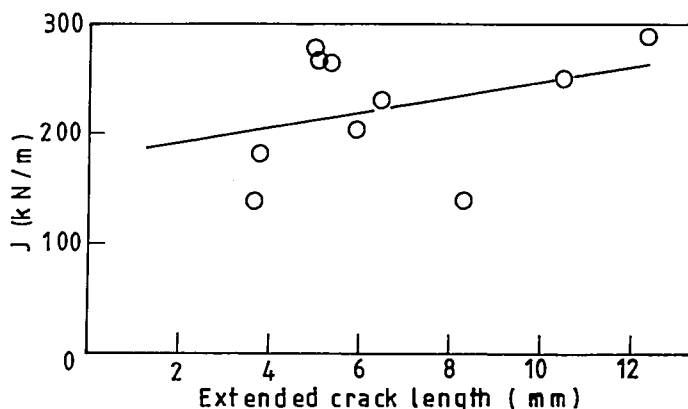


Fig.5 Correlation of J values and extended crack length for several tested steel

Table 1. Obtained results of J values on several steel

Steel	carbon content	micro structure	J values
	wt%		kN/m
S15C	0.15	coarse pearlite	280
	0.15	fine pearlite	305
	0.15	fine pearlite	150
S25C	0.25	fine pearlite	370
	0.25	coarse pearlite	250
	0.25	coarse pearlite	350
S55C	0.55	coarse pearlite	225

come from the experimental difficulties. Some scatter of test results come from the complicated slip and branching of crack. But the tendency of hardness or microstructure factor is still not very clear. Only it was shown that the microstructures are affecting to the J_{Ic} values.

IV. Conclusion

Several types of steels are tested for J_{Ic} evaluation by changing the condition of carbon content and heat treatment condition. The resistance curve method is employed for J_{Ic} measurement and obtained values are distributed between 150 to 370 kN/m. The tentative value of declination in resistance curve is calculated from the experience of this experiment on the conventional heat treated steel. The J_{Ic} values reasonably correspond to the values listed in the references and those values show clear microstructure dependence. But final fracture surfaces show fairly complicated slip plane and branching propagation of cracks. Therefore further detailed analysis is required to the precise determination of fracture toughness on the steels with various microstructures.

Acknowledgment

All the results which are shown here are cited from the graduation thesis of Mechanical Engineering Department from 1988 to 1992 in Material Research Laboratory. I here express my gratitude for their great contribution.

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